Hemispherical Reflectance Measurement Field Instrument Design

Final Report

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Pacific-Sierra Research Corporation
Los Angeles, CA

PSR Report 2183

SWOE Report 91-17
July 1991

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FOREWORD

SWOE Report 91-17, July 1991, was prepared by T.W. Liepmann of Pacific-Sierra Research Corporation, Los Angeles, California.

This report is a contribution to the Smart Weapons Operability Enhancement (SWOE) Program. SWOE is a coordinated, Army, Navy, Marine Corps, Air Force and DARPA program initiated to enhance performance of future smart weapon systems through an integrated process of applying knowledge of the broadest possible range of battlefield conditions.

Performance of smart weapons can vary widely, depending on the environment in which the systems operate. Temporal and spatial dynamics significantly impact weapon performance. Testing of developmental weapon systems has been limited to a few selected combinations of targets and environment conditions, primarily because of the high costs of full-scale field tests and limited access to the areas or events for which performance data are required.

Performance predictions are needed for a broad range of background environmental conditions and targets. Meeting this need takes advantage of significant DoD investments by Army, Navy, Marine Corps and Air Force in 1) basic and applied environmental research, data collection, analysis, modeling and rendering capabilities, 2) extensive target measurement capabilities and geometry models, and 3) currently available computational capabilities. The SWOE program takes advantage of these DoD investments to produce an integrated process.

SWOE is developing, validating, and demonstrating the capability of this integrated process to handle complex target and background environment interactions for a world-wide range of battlefield conditions. SWOE is providing the DoD smart weapons and autonomous target recognition (ATR) communities with a validated capability to integrate measurement, information base, modeling and scene rendering techniques for complex environments. The result of a DoD-wide partnership, this effort works in concert with both advanced weapon system developers and major weapon system test and evaluation programs.

The SWOE program started in FY89 under Balanced Technology Initiative (BTI) sponsorship. Present sponsorship is by the U.S. Army Corps of Engineers (lead service), the individual services, and the Joint Test and Evaluation (JT&E) program of the Office of the Director of Defense Research and Engineering (DDR&E), Office of the Secretary of Defense (OSD).

The Program Director is Dr. L.E. Link, Technical Director of the U.S. Army, Cold Regions Research and Engineering Laboratory (CRREL). The Program Manager is Dr. J.P. Welsh, CRREL. The Integration Manager is Mr. Richard Palmer, CRREL. The task areas and their managers are as follows: Modeling Task Area, LTC George G. Koenig, USAF, Geophysics Laboratory (GL), of the Air Force Phillips Laboratories; Information Bases Task Area, Mr. Harold W. West, PE, U.S. Army Engineer, Waterways Experiment Station (WES); Scene Rendering Task Area, Mr. Mike Hardaway, Corps of Engineers, Topographic Engineering Center (TEC); Validation Task Area, Dr. Jon Martin, Atmospheric Sciences Laboratory (ASL) of the Army Materiel Command.

PREFACE

This final report describes a field reflectometer design produced under small business innovation research (SBIR) program Phase I funding. The work was sponsored by the U.S. Army Atmospheric Sciences Laboratory (ASL), White Sands Missile Range, New Mexico, under contract no. DAAD07-91-C-0125.

The contract period was 27 February 1991 through 26 August 1991. The contract technical representatives were Dr. Jon Martin and Mr. Frank Eaton, both with ASL.

SUMMARY

This Phase I small business innovation research (SBIR) final report describes the design of a man-portable, bidirectional reflectometer field instrument. The instrument can irradiate any sample surface with several spectral bands of radiation (ultraviolet, mid-infrared, and long-infrared) and measure the reflectance over a near-hemispherical region. The data from this reflectance measurement can characterize the bidirectional reflectance distribution function (BRDF) of the sample. The source illumination angle is varied, and a complete BRDF characterization can be obtained for each of a possible 90 illumination angles. The instrument is automatic and has self-test and self-calibrate features. The computer that controls the test also gathers the digital data that can be immediately transferred over a serial (i.e., RS232) or parallel (i.e., IEEE 488) data link. The vacuum sample stage is designed to securely hold foliage specimens in place without removal from the plant. This stage can be moved aside for other samples (i.e., rocks, limbs, ground, etc.). The low profile of the device allows the unit to rest directly on the sample to be tested permitting tests of road surfaces, grass fields, plastic sheeting, etc. This instrument has two pieces--a sensor unit and a control/power unit. These are field units which can be powered from an automobile cigarette lighter or a 12-V battery belt.

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SECTION 1
INTRODUCTION

On 27 February 1991, Pacific-Sierra Research Corporation (PSR) was awarded a small business innovation research (SBIR) Phase I contract from the U.S. Army Atmospheric Sciences Laboratory (ASL), White Sands Missile Range, New Mexico, to design the Hemispherical Reflectance Measurement Field Instrument (HRMFI). Completed during this effort was a requirements analysis, identification of commercial detectors suitable for the HRMFI, analytical radiometric design, control system concept, and opto-mechanical layout. No significant technical problems were encountered, and the expected design performance exceeds the ASL requirements. Table 1 outlines the performance specifications of the design, and Fig. 1 shows a schematic of the HRMFI. Section 1 reviews the Phase I goals, Sec. 2 outlines the HRMFI design requirements, Sec. 3 discusses potential HRMFI applications, and Sec. 4 presents the conclusions.

Table 1. HRMFI Specifications.

Attribute	Specification	Units
Test area diameter	200	mm
Reflectance measurement range	0.01 to 1.0 (specular or diffuse)	--
Wavelength of spectral bands	UV 0.25 to 0.40 Mid-IR 3.0 to 5.0 Far-IR 8.0 to 14.0	μm
Source solid angle	0.215	sr
Hemispherial angular resolution	0.26 (93 samples over hemisphere)	rad
Time to make one measurement	15 to 45	min
Computer controller	Intel 80386	--
Interface	IEEE488 or RS232	--
Peripherals	Video keyboard 3 1/2 in. floppy disk	--
Size	Unit 1 1200 × 1200 × 600 Unit 2 600 × 600 × 300	mm
Weight	Unit 1 = 18 Unit 2 = 12	kg
Input power	12 VDC at 15 amps	--
Ambient temperature	0 to 40	deg C
Man-portable	Yes	--
Field-operable	Yes	--
Weather-resistant	To light rain and wind	--

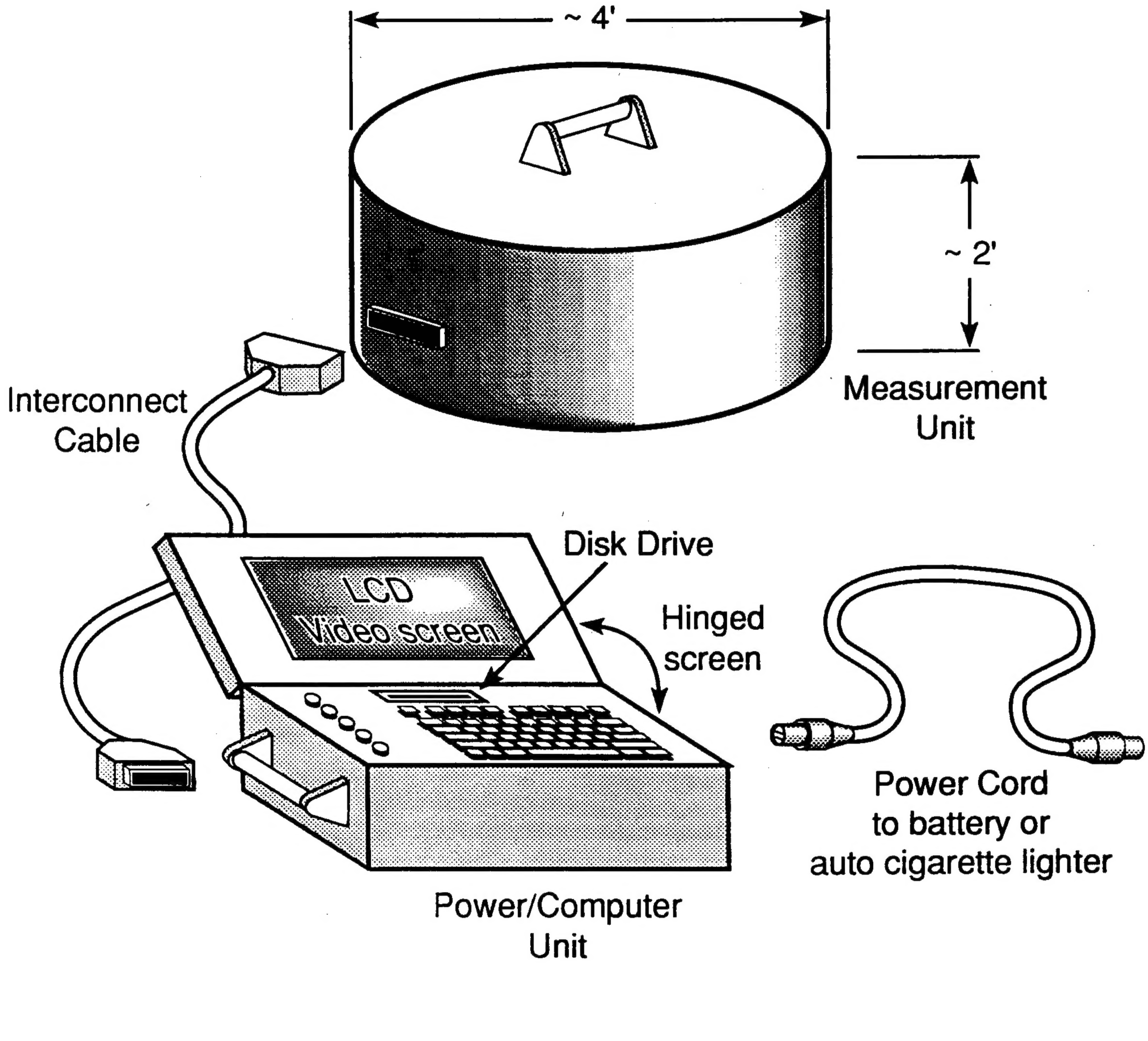


Figure 1. HRMFI System Components.

SECTION 2
OBJECTIVES

The goal of this Phase I effort is to design a practical HRMFI. The HRMFI mission is to measure the complete BRDF for a sample between 6 to 12 in. in diameter.

The BRDF characterization will be performed in three wavelength bands: ultraviolet (UV) (300 to 400 nm), mid-infrared (IR) (3 to 5 μm), and far-IR (8 to 14 μm). The measurement will consider both the source illumination angle and the energy reflected into the hemisphere above the sample. The sensitivity of the HRMFI will be sufficient to characterize a flat diffuse sample assuming a reflectivity of 1 percent in the UV and 7 percent in the IR. Narrow spectral bandwidth sources are not required.

The HRMFI will permit the reflectance qualities of a sample of plant foliage to be measured without removal from the plant. Vegetation samples swiftly change in character once removed from the plant, so accurate reflectance measurements of a plant's BRDF must be made on living samples. The HRMFI will incorporate a stage to hold and orient the sample for the test.

All aspects of the BRDF measurement are to be automatically controlled by the computer control system. Computer control has the advantage of making the complex, repetitive BRDF measurement reliable and fast. Self-test and self-calibration will be incorporated to assure that the data collected by the device is accurate.

The HRMFI will be usable in a laboratory or field environment. Most of the samples that are of interest to ASL exist naturally out-of-doors, so the HRMFI is to be primarily designed as a field instrument. However, it must be provided with an AC power converter so that it can just as easily be used in the laboratory. The power the HRMFI requires will be kept low, so the device can be powered by an automobile cigarette lighter. As the weather is unpredictable, the HRMFI should be weather resistant, although making the instrument weather-proof is not essential.

SECTION 3
DETAILED DESIGN DESCRIPTION

This section describes the PSR HRMFI design, which is fully compliant with the Phase I goals. Presented here is a design overview followed by descriptions of the design details.

3.1 DESIGN OVERVIEW

The Phase I design effort results indicate that a single type of detector ($LiTa0_3$ pyro-electric) can cover all of the required wavelength bands with sufficient sensitivity that realistic, man-portable radiation sources can be used. The power required by the non-laser sources is modest (less than 40 W), yet the worst case signal-to-noise ratio (SNR) is 1 at the lowest total diffuse reflectances specified by ASL (1 percent in the UV; 7 percent in the IR). Thus, the design is conservative and represents low technical risk. In addition, PSR has identified several methods to increase SNR of the measurements thereby increasing the sensitivity and further reducing the technical risk.

The use of broad-band, pyro-electric detectors provides the HRMFI with the flexibility to add other wavelength bands, limited only by the detector window transmission. Adding new wavelength bands within the 0.25 to 14 μm range, such as visible (VIS) or near-IR (NIR), would not require significant hardware modification to the HRMFI. Software modifications may be required, however, this task could be included in a Phase II effort or implemented by ASL. Microphonic effects and electrical noise are mitigated through the use of small (2 mm^2), commercially-available, visoelastically-mounted $LiTa0_3$ detectors with an integral field effect transistor (FET) preamplifier. These detectors provide an detectivity of about 5×10^8 cm-$Hz^{1/2}$/W for a 15-Hz chopping frequency. They operate at room temperature and are insensitive to background radiation (which has a low modulation frequency), hence, are ideal for this field instrument. (Similar detectors are used in motion sensors for commercial applications.)

The reflectance data is acquired as analog output and converted to digital information by onboard, commercial analog-to-digital (A/D) circuitry and Intel 80386 processor-based computer system. Synchronous detection will be implemented in a combination of software and electronic hardware. As the worst case SNR is unity, extremely narrow bandwidth detection will not be necessary, thereby enabling high dynamic range for

measuring a wide range of reflectivities (to 100 percent) for diffuse and specular samples.

The system is controlled by the same computer through PSR's standard stepper-motor drive system. This includes the detector arm position, source arm position, and source rotation. The computer also controls the source output band, filter position, chopper speed, and calibration standard insertion through solid-state circuitry, motors, and solinoids. Microphonic vibration resulting from control operations is allowed to die out before detectors are interrogated. The data acquisition is to take from 15 min to 1.5 hr depending on the features and trade-offs selected by the instrument user.

3.2 DETECTOR MODULE DESIGN

The Phase I effort indicates that two commercially-available detectors have sufficient sensitivity for the HRMFI application. (Using commercial equipment speeds up development and reduces the technical risk. PSR endeavors to use this advantage as much as possible, and the HRMFI design is sufficiently flexible that about 65 percent of the device will consist of commercial parts.)

The baseline design utilizes EDO/Barnes 2-mm^2 pyro-electric detectors with integral FET preamplifiers and viscioelastic microphonic isolation mounts. Figure 2 shows a diagram of one of these detector/preamplifier assemblies and the pyro-electric spectral response. Pyro-electrics are much less sensitive than most types of detectors; however, in this application, their wide, flat spectral response is required. As they have sufficient sensitivity for the job, these detectors are ideal. The detector package will be connected to the mating main amplifier, track-and-hold (TAH), and 12-bit A/D converter (ADC). This electronics is discussed below (Sec. 3.3) in more detail. An alternate detector module produced by Laser Precision has equal capability, however, it is slightly larger and heavier than the baseline sensor (detector area is 1 cm^2). The detector modules are mounted into a detector arm which is described in Sec. 3.5.

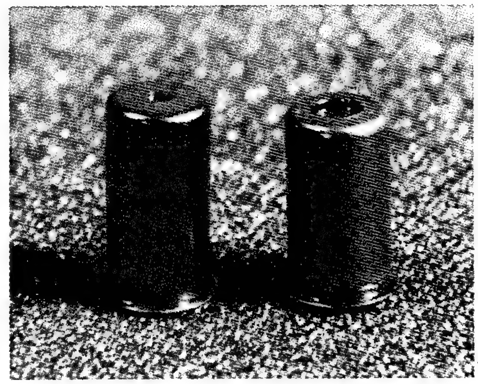
The design uses a standard, calibrated diffuse reflector sample for automatic detector calibration. Diffuse standards are readily available (commercially) with 98 percent accuracy and a range of reflectivities.

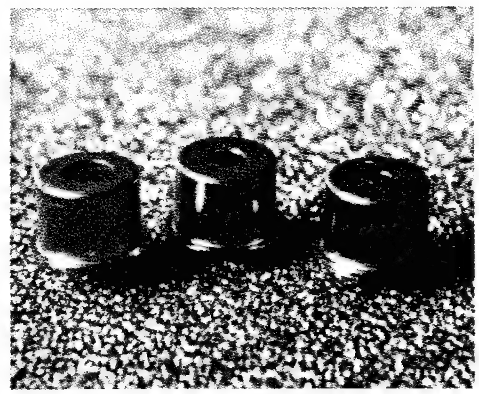
3.3 CONTROL AND DATA ACQUISITION SYSTEM DESIGN

A control computer will allow the HRMFI to operate autonomously and automatically and allow for digitally-implemented synchronous data acquisition.

HYBRID DETECTORS/PREAMP

kT-2200 SERIES	kT-2200	kT-2220	kT-2230
Element Diameter (mm)	1.0	2.0	3.0
Voltage Responsivity (20 Hz) min. v/w	300	100	50
NEP (20 Hz, 1 Hz), max. W/.Hz$^{1/2}$	1.4×10^{-9}	2.1×10^{-9}	3.0×10^{-9}





Spectral Response (detector element). . . . 0.4μ to 40μ (i.e. kT-3100)
Frequency Response (detector element) . . 2Hz to 2kHz
Maximum Recommended Power Density. .10W/cm2
Operating Temperature . . . . –30° to 75°C
Window* . . . . Irtran II
Suprasil
No Window
Dimensions. . . . . TO-5 can type
.327 ± .002" dia.
.630 ± .010" length
Power Requirement. 6–20Vdc
Input, Putput Connection. . . . . 3 pins, 0.2" B.C.

*** Window affects detector spectral response. See transmission curves. Use same window identification suffices as for kT-3000 Series. Quoted NEP for windowed detectors only.**

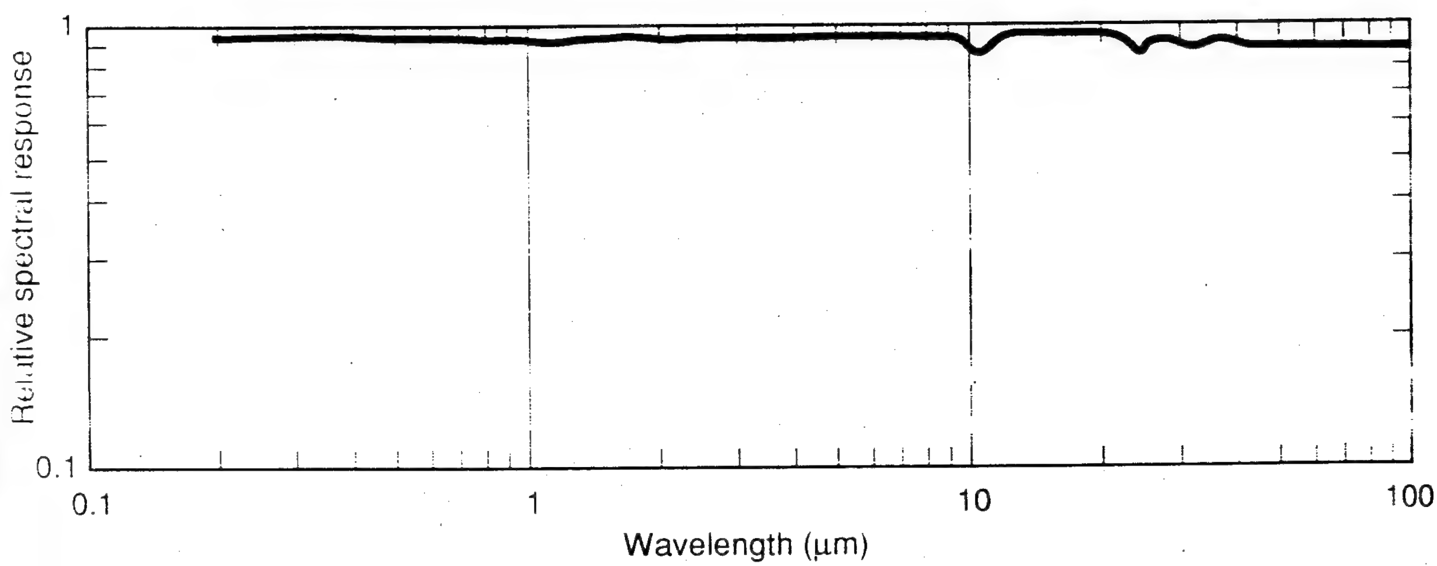


Figure 2. Detector subassembly and pyroelectric spectral response.

Figure 3 shows the control method schematically. This computer will consist of a commercial, embeddable INTEL 80386 microprocessor computer. This will provide the computational speed and flexibility to assure that the HRMFI digital data processing and control functions can be implemented easily. An analysis of the data rates indicates that there will also be significant excess computer power to allow for additional functions to be added, such as data compression or autonomous, real-time plotting of the measurement results. The design uses a commercial computer product which will reduce development time and cost as well as increase reliability and maintainability of the HRMFI. In addition, it will allow standard IBM-format disks to be used for command files and software updating or modification. This flexibility will ensure the HRMFI has a long, useful life. In addition to the features already mentioned, the baseline single board controller has full support built-in for video display, keyboard, floppy, and/or hard disks. Also, the open architecture allows for the addition of standard expansion boards (i.e., IEEE 488, etc.). In fact, real-time control of the system is possible via any standard communications protocol should host computer control be desired. Finally, the board has 1 Mbyte of RAM, a ROM disk, and it can "boot up" from the firm ware (EPROM) or the floppy disk drive. Thus, the HRMFI can be set up to run any number of test programs without modification. This would be especially useful for testing different sets of samples for which different wavelength bands or special measurement conditions are required. For example, a high resolution examination of a particular portion of the hemisphere could be put on a separate disk for repeated use on a special measurement assignment. Alternately, a menu of tests may be run from a single disk. Finally, the controller board supports a parallel and serial printer port, so that hardcopy output can be obtained even during autonomous HRMFI operation. This would be used to provide test logs for documenting the exposure levels and illumination parameters following each test or to review the results immediately.

The interface electronics serve to facilitate the computer's control of the sources, various mechanical control subsystems, and detectors. Controlling the HRMFI will require that the computer be able to reliably communicate, actuate, and input the status of the various HRMFI active subsystems. Since each type of subsystem has a different input requirement, some kind of interface circuitry will be necessary. For example, one circuit will translate the control computer's commands into the required electrical signal for driving the detector arm to the next scan position. The detector and source arm positioning motors will use the standard PSR dual motor, microcontroller-based microstepping driver for this task. This subsystem communicates to the control computer via a standard RS232 serial interface and uses a proprietary electrical damper

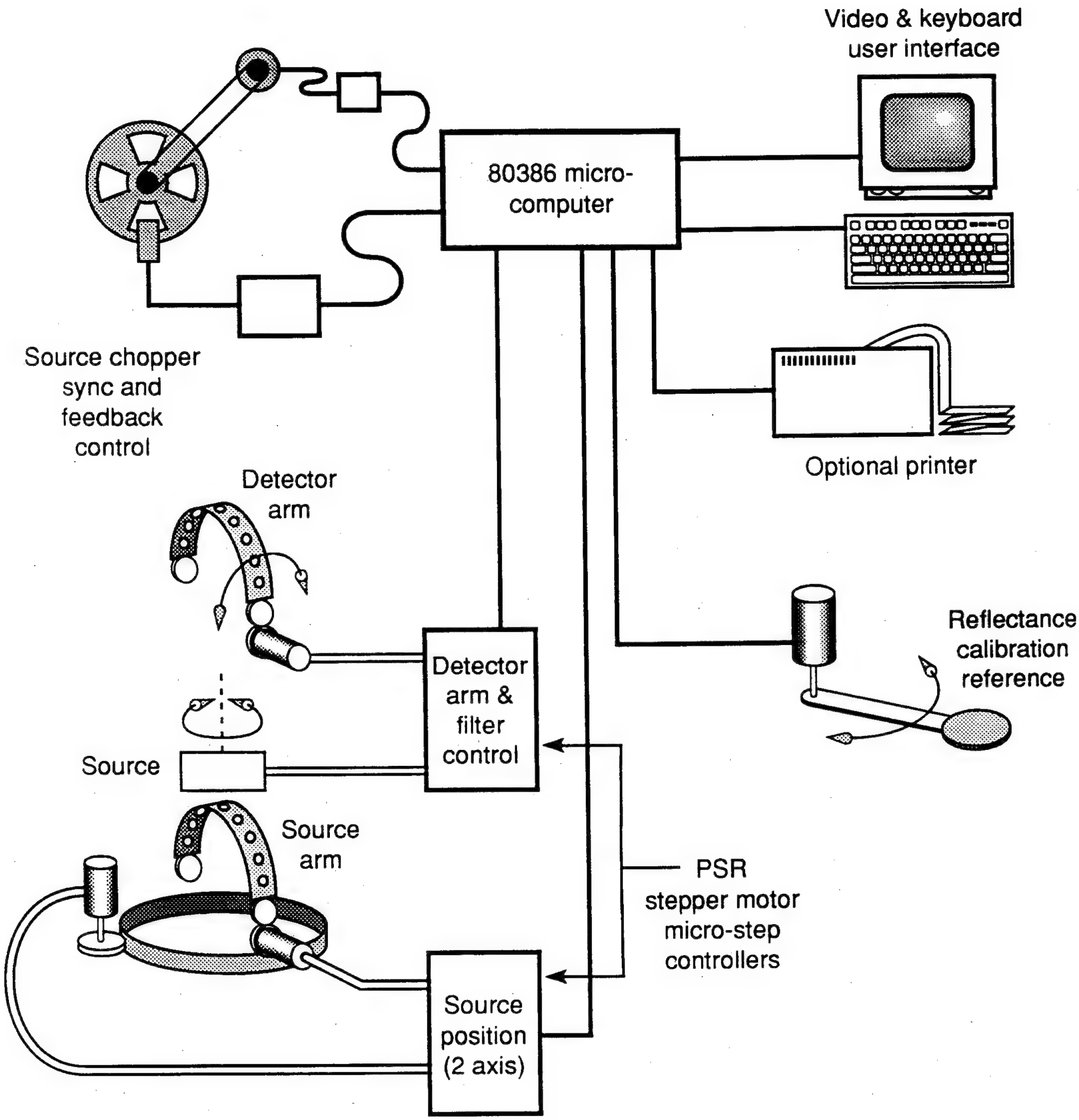


Figure 3. HRMFI control scheme.

for smooth, error-free, open loop position control (similar to that used in computer disk drive head positioners). The source azimuthal position motor and the IR filter wheel will be similarly controlled. The sources will be modulated by a commercial Boston Electronics servo-motor chopper wheel system. This will be interfaced to the computer via the standard interface of the chopper and the modulation detector via the chopper's light-emitting diode (LED)-phototransistor frequency monitor. This frequency monitor will use a section of a special chopper wheel that has a modulation frequency that is 20 times that of the sources assuring high resolution frequency detection for precise chopper control for high synchronous detector accuracy. A simple buffer and digital-to-analog converter (DAC) are all that is required for interfacing, synchronizing, and controlling the chopper with the computer. The final example of interface electronics is the detector synchronous detection and digitizing electronics. This will consist of separate amplifiers. TAH and 10-bit resolution A/D converter (which are commercially available and combined on a single integrate circuit) for each of the pyro-electric detectors. The TAH is strobed by the computer to synchronize the data acquisition to the chopper.

Where possible, commercial electronics will be used for interfacing. Several sources for motion control have been identified (i.e., Newport Corporation, Ealing Electro-Optics, etc.). All offer circuit cards that are compatible with the control computer described above, hence, a little custom software development and cabling are all that some of the interfacing tasks will require. As these examples demonstrate, none of the custom interface development is very complex or state-of-the-art. PSR expects that all of this type of circuit development can be accomplished with standard transistor-transistor logic (TTL)-type integrated circuits where it cannot be obtained commercially. Intelligent (i.e., microcontroller-based) electronics will not be required for these tasks (except for the stepper-motor control, where the development is already complete), due to the simplicity of the interface subtasks.

3.4 SOURCE ASSEMBLY DESIGN

The HRMFI source subsystem is designed to produce a stable, narrow wavelength, low divergence beam of radiation for illuminating the sample. Figure 4 shows the source subsystem design. Measuring the reflectance requires that the sample be illuminated with a known amount of radiation so that the reflected energy can be compared to that from a reflection standard. It is desirable that the radiation sources produce a stable output, since that will make monitoring the source output unnecessary. The two sources that can be incorporated into the HRMFI are a commercially-available, compact

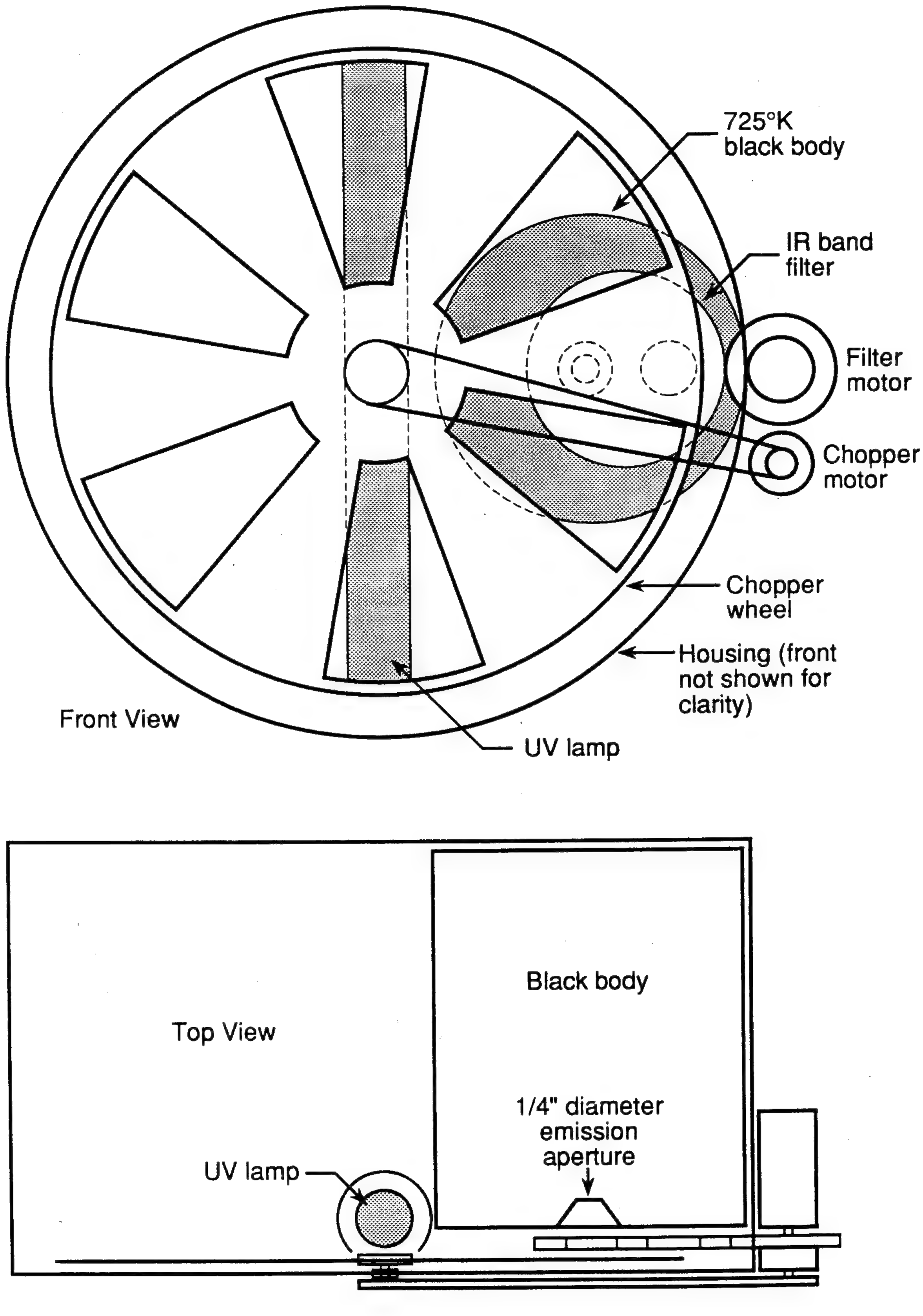


Figure 4. HRMFI source diagram.

725 deg K blackbody (Electro-Optical Industries) and a mercury discharge lamp (Oriel). The blackbody will produce the IR radiation, and standard commercial bandpass optical filters will be used to restrict the output to the required range of wavelengths (3 to 5 and 8 to 14 μm). The commercial blackbody is specified to control the temperature to within 2 K in the worst case, which produces a maximum radiance change of 1.1 percent. Thus, this source will contribute a maximum error of 1.1 percent of the measured reflectivity. The stability of the Oriel UV lamp is good (2 percent, worst case) after a 30-min warm-up. This lamp outputs 90 percent of its radiance at the 253.7 nm mercury line and requires only about 38 W of power. The UV lamp will incorporate a simple cylindrical reflector to double the useable output radiation. A fluorescent blacklight (such as the General Electric F4T5/BLB) also could be used which provides an equal amount of radiation in the 300 to 400 nm band. This lamp is much larger, however, it only requires 10 W of input power.

The source subsystem output must have a narrow beam angle so that the source illumination angle can be defined to sufficient precision. The BRDF measurement requires that the angle of illumination be determined by the desired angular resolution. In other words, if the source beam angle is 40 deg, then the maximum BRDF angular resolution will be approximately 40 deg. The HRMFI will restrict the incident beam to a 30 deg angle. This will be sufficient to unambiguously resolve 144 reflectance angles over the hemisphere ($\sim [360/30]^2 = 144$). The reflectance resolution is less than this, so the source beam is sufficiently narrow for the HRMFI. The blackbody geometry determines its output radiation angle and is designed to be 30 deg. The UV lamp output must be tailored by aperture stops. Overfilling is avoided to prevent the HRMFI from measuring the reflected radiation from surfaces other than the sample's.

The two sources will be mounted together into a single, compact enclosure with a single chopper wheel. When a device is simplified, reliability is increased and weight, power usage, and development costs are reduced. One way to simplify a system is to use as few parts as possible. The PSR design combines the two sources into one small housing so that a single chopper wheel can modulate all of the sources. This simplifies the computer interface and reduces the computational overhead that would be required for two choppers. Since the design places the two sources close together (approximately 3 cm apart), there is only a small difference in their apparent angle of incidence (approximately 4 deg). Using a filter wheel to select the IR-band from a single blackbody reduces the number of sources. This also speeds the data acquisition, since data can be acquired at two wavelength bands for each source position. This arrangement will also allow other wavelength bands to be added with little hardware

modification as the same housing, chopper, detectors, and data capture system will work with any wavelength from 250 to 14,000 nm. This range of wavelengths is determined by the detector window material (barium fluoride) whose spectral transmission is plotted in Fig. 5.

3.5 STRUCTURE AND HOUSING DESIGN

The optics, source subsystem, detector modules, and control electronics need to be housed in a weather-resistant, man-portable structure.

The purpose of the structure is to provide the HRMFI components with a light-weight, light-tight, and weather-resistant housing in which to operate. This housing will allow access to all the vital components for sample changes, maintenance, and repair. It will also provide the support and actuation required to manipulate the sources and detectors as required. The housing will not be weather proof, as the HRMFI is not expected to operate in the field in poor weather. (Such a housing could be built, however, it would carry considerable penalty in cost, weight, and portability.) The housing design uses an open truss skeleton sheathed with a thin (1/16 in.) aluminum or fiberglass skin. This type of structure is light weight and strong and provides good resistance to weather.

The geometry of the detector and source positioning mechanism is designed so that no sample rotation or motion is required to complete the BRDF at all three bands. This is necessary for characterizing most samples. This design requires that the source angle of incidence be systematically varied over the hemisphere, and the detectors sample the reflected energy at all sample points over the hemisphere for each source position. To do this, PSR has devised an arrangement in which several detectors are mounted to a semi-circular arm that pivots on an axis close to the sample plane. This arm with its detectors samples the complete hemisphere above the sample in one sweep of 180 deg (one-half revolution). The sources are mounted to a similar arm, except this arm has a larger radius so as to clear the detector arm. Also, this arm is mounted to a rotation stage that rotates the axis of the source in the plane of the sample. Thus, the two arms can operate independently without interference, and the source angle of incidence can be varied over the entire hemisphere. Figure 6 shows the baseline design detector and source configuration.

Stepper motors are used to actuate the mechanism under computer control. Spur gear boxes are used to increase the torque and resolution of these motors so that they can move the source arm, detector arm, and rotate the source arm mounting in azimuth. Spur

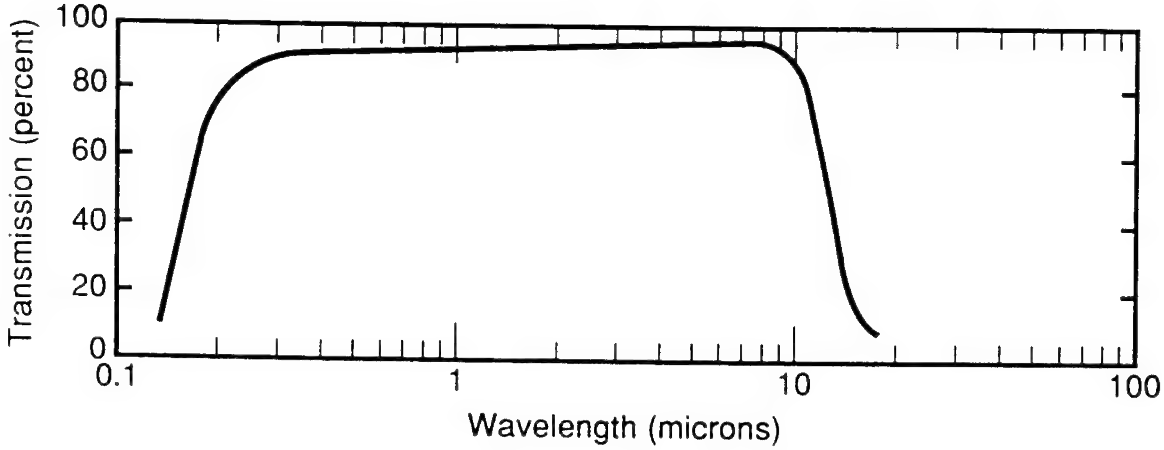


Figure 5. HRMFI detector window transmission.

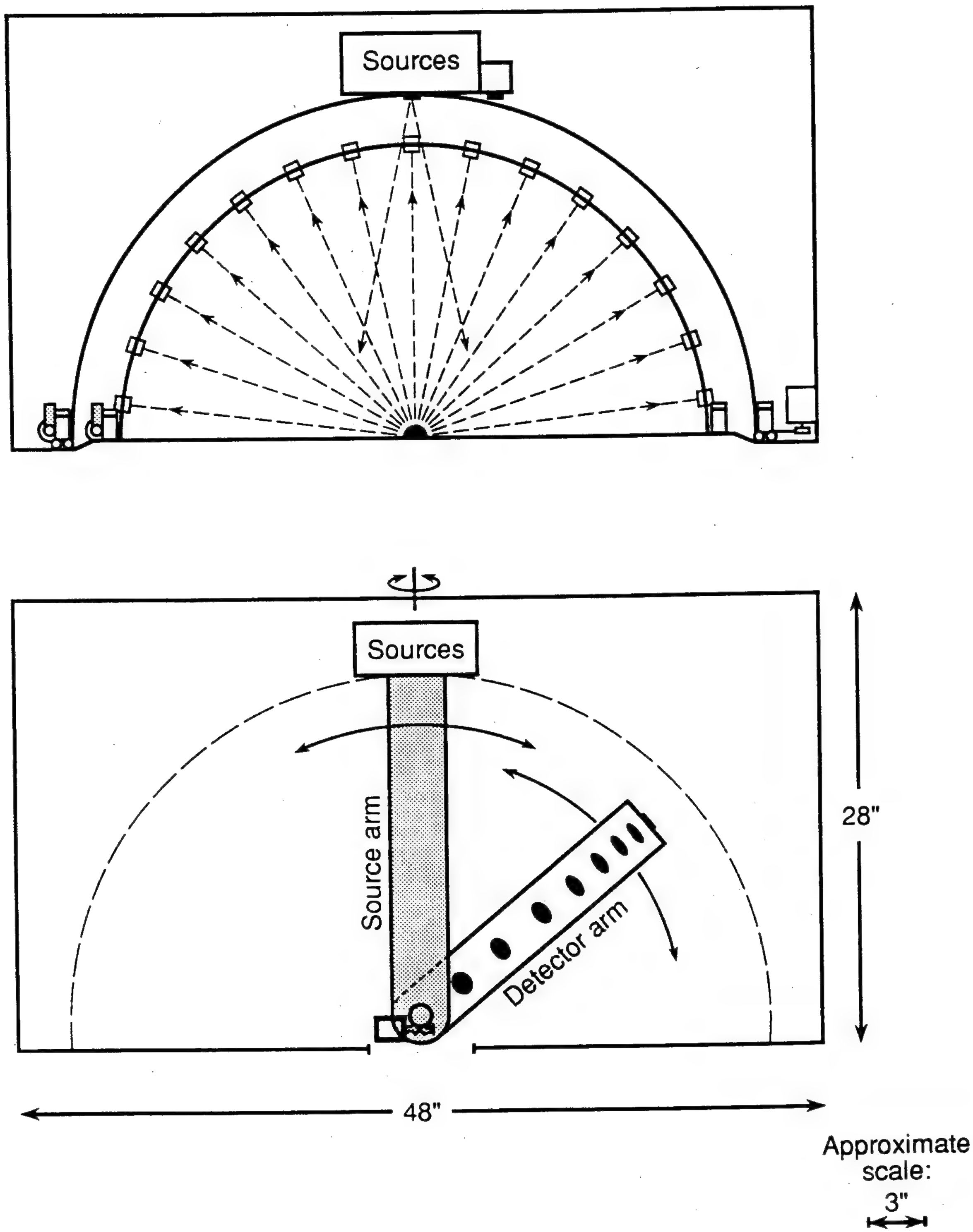


Figure 6. HRMFI source, detector, and housing.

gears are superior to worm gears, in that they can be "back-driven" (mechanism moved manually) without damage. Both source and detector arms utilize very similar mechanisms.

The only external support that will be required will be 12 VDC at an estimated 20 amps of electrical power. A 30 amp-hour battery belt can be used to provide this level of power, or the unit can be connected to a car via a cigarette lighter.

3.6 SUPPORTING SUBSYSTEMS DESIGN

The HRMFI requires an operator's console, sample stage, and a power system.

3.6.1 Operator Console

The operator's console is designed to control all of the functions so the HRMFI can operate completely autonomously. The design calls for a keyboard, video display, and floppy disk, so the system can be programmed to run any reflection test that is required. This program can be stored and recalled from the floppy disk. A printout of the programmed tests can be made via the printer port. A ROM resident program will make programming the tests a simple menu selection process. Alternatively, a completely different program can be run from disk such as a diagnostics program for system trouble-shooting.

3.6.2 Sample Requirements

The measurement of the reflection of energy from a surface depends on the surface's geometry. The BRDF generally has no meaning unless the orientation of the sample is known. This is due to the averaging of the reflection effects over the sample area which is intrinsic to the HRMFI method of measurement. Therefore, the HRMFI requires some method of defining this orientation if the material BRDF is to be determined. For example, a purely specular hemispherical reflector will seem to have the reflectivity distribution of a diffuse material. This result is correct if determining the BRDF of the sphere is the mission. However, if the goal is to measure the BRDF of the material that the sphere is made of, then the measured BRDF will not be the correct one. Therefore, using the HRMFI must be limited to flat samples if measuring the material BRDF is desired. All discussion of samples below assume that the material sample is to be flat and fills the sample area.

The vacuum sample stage will allow for holding vegetation or other thin samples securely while keeping them flat. Thin samples can bulge or distort, producing a three-

dimensional shape that alters the BRDF. The HRMFI vacuum stage will pull these types of samples securely against the flat orientation surface. This will constrain the sample to a plane and will work with most samples, including vegetation. The alternate method, which is to press the sample against a window or screen, is impractical for several reasons. First, windows and screens have their own BRDF which may limit the instrument sensitivity. Secondly, the few materials that are transparent at the wavelengths of interest (250 to 1400 nm) are fragile and environmentally sensitive. This is unsuitable for a field instrument where windows are subject to scratching, cleaning, etc. (The windows on the pyro-electric detectors are small and protected from the outside environment.)

The sample stage is designed to be removable from the HRMFI for measuring other sample types. Some samples may be too large to be correctly called "samples". Road surfaces, areas of ground, etc., are too large to be conveniently "placed" onto a sample holder stage. Thus, the HRMFI is designed so that it can be placed directly onto the surface under test (SUT). This will greatly simplify setting up the measurement of large "samples".

3.6.3 HRMFI Operation

The HRMFI setup procedure would involve only a few steps: positioning the test unit housing onto or near the sample, locating the sample onto the vacuum stage (small, flat samples), connecting the power unit to the battery and test unit, and initiating the test program. At this point, the system is ready to illuminate the SUT with the pre-programmed source radiation and commence the BRDF measurement sequence. The radiation output at the HRMFI sample stage is eye safe, except for extended viewing of the UV source, which could result in photochemical cataract. This is due to the nature of the invisible UV radiation.

3.6.4 Power Unit

The power unit of the HRMFI will house the operator's console and provide filtered electrical power and control signals for the HRMFI measurement unit. Figure 7 shows the baseline design of the power unit. Pyro-electric detectors are sensitive to many kinds of noise: electrical, vibration, EMI, etc. The effect of noise can be easily mitigated by distancing the sources of noise from the detectors. The EMI is reduced by housing the computer (which produces EMI) in a separate, shielded unit. Filtering the electrical power to the HRMFI further eliminates noise from being transmitted via the power source. Finally, having the operator's console separate from the measurement unit

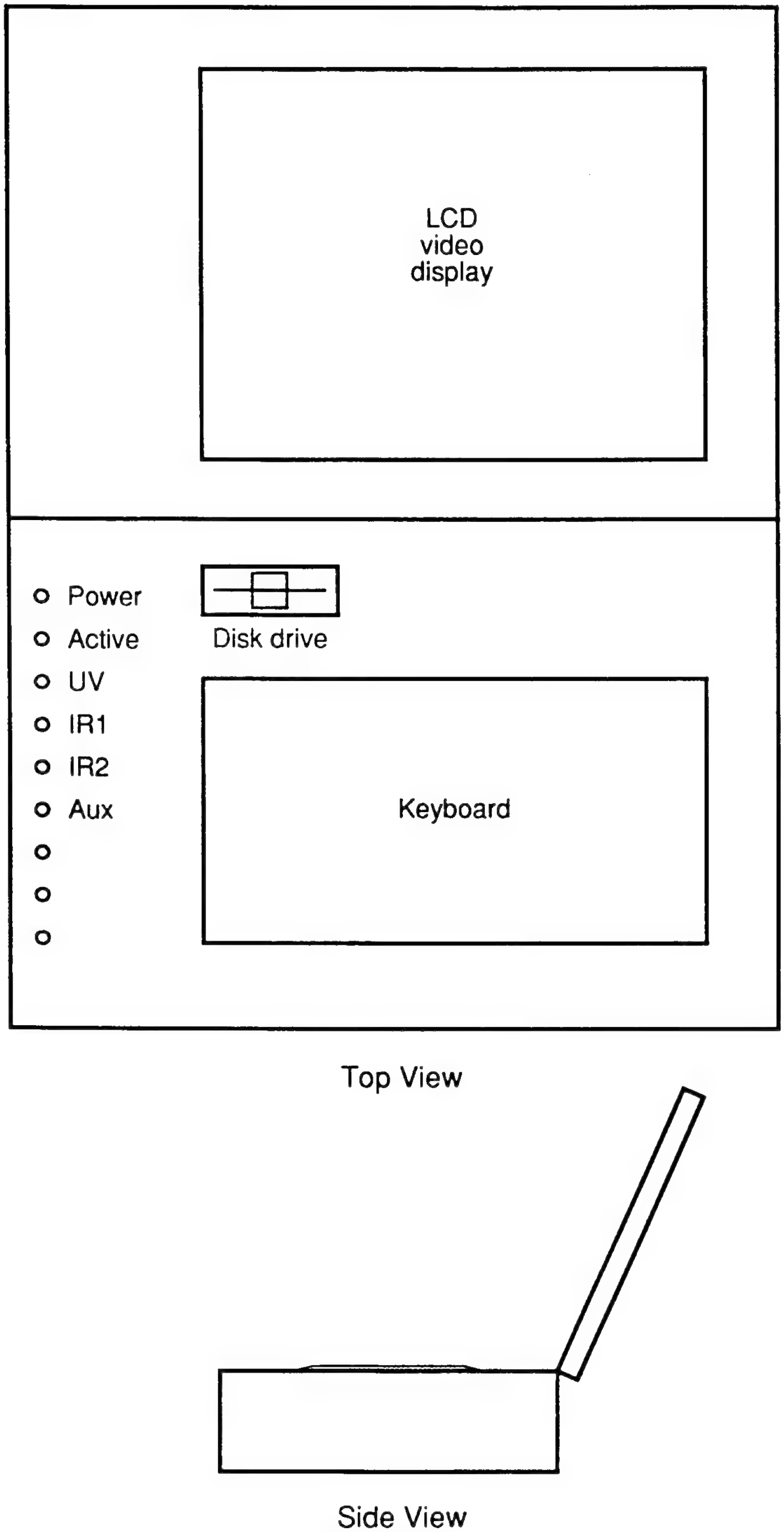


Figure 7. HRMFI power/control unit.

prevents vibration due to the operator (i.e., keyboard use, disk access, etc.) from reaching the sensors. This design will increase the measurement sensitivity by decreasing the overall system noise level.

3.7 MEASUREMENT SPEED ESTIMATE

PSR has analyzed the HRMFI measurement speed and designed a practical methodology which seeks to minimize the time to measure the BRDF. Each characterization requires that sample measurements of the reflected radiation over the hemisphere above the sample be taken for each source angle of incidence and wavelength. This takes either a larger number (~ 100) of detectors or a mobile subset (~ 12). Therefore, while great speed can be obtained using a large number of detectors, (BRDF in 15 min at all three bands), the complexity and inflexibility of this arrangement seems to outweigh the speed advantage. The baseline design uses a rotating, semi-circular arm with 12 detectors evenly spaced on it. This arrangement provides a good balance of speed, flexibility (resolution can be adjusted in software), and simplicity.

To analyze the measurement speed, PSR used a baseline resolution of 12 detector arm positions and 90 source positions on the hemisphere (consistent with Table 1). Conservatively, PSR estimates the detector and source arm re-positioning time is 1 s, with another 1 s of settling time to reduce microphonics. Further, the time to acquire the irradiance data for each wavelength is also estimated to be 1 s. Thus, the measurement at each detector arm position requires approximately 5 s. In addition, there are 12 detector arm positions for each of the 90 source positions (i.e., angles of incidence). Thus, the total measurement time is approximately [5 x 12 x 90 s = 5400 s (90 min)]. Thus, a complete BRDF characterization of three wavelength bands will take about 90 min, not including setup time. Increased speed is possible by reducing the number of source or detector positions which is software selectable. Therefore, the BRDF measurement resolution and measurement time can be tailored by the operator to a particular mission without hardware modifications.

PSR expects that detector and source repositioning can be made faster, and this data acquisition time represents conservative estimates. PSR's proprietary microstepping step motor controllers have a measured rotational speed of at least 170 deg/s. Assuming that a ten to one gearing is required for the detector or source arm positioning, the arm speed will be about 17 deg/s, or about 0.7 s to reposition the arm. In addition, higher torque motors can reduce the required gear ratio and time required to reposition the arms, and this data acquisition time represents conservative estimates.

3.8 COST ESTIMATE

PSR has compiled a preliminary list of equipment and materials which would be required for HRMFI implementation. Costs associated with those materials are shown in Table 2.

Table 2. Materials Cost Estimate

Item	Quantity	Source	Total Cost ($)
Blackbody	1	Electro-Optic Industries	5,100
UV lamp	1	Oriel	310
386 computer	1	TBD	2,150
Detectors	12	TBD	4,800
Electronics	1	Custom	5,500
Motors	4	Sloysyn	800
Chopper	1	Boston Electronics	1,050
Miscellaneous mechanical	1 set	Custom	6,120
Gear box	3	TBD	1,060
Sample stage	1	Custom	3,100
Power filter	1	Custom	1,200
Housing	1	Custom	2,160
TOTAL			$33,350

SECTION 4
ANTICIPATED BENEFITS OF DESIGN IMPLEMENTATION

This Phase I effort provides the design for an instrument that can measure the BRDF of any type of sample for many applications. The uniqueness and broad utility of such measurements suggest that production of the HRMFI will be beneficial in many ways. Examples of the utility of the HRMFI data include performance prediction for aircraft, ground vehicle, and naval vessel-based sensor systems. The data could also be used to infer the performance of satellite sensors. Since the background reflectivity characteristics strongly affect the sensor performance, measurements on a broad range of materials should be made. Many of these samples cannot be measured reliably in a laboratory, so the HRMFI's ability to measure the BRDF in the field is valuable. Also, the software used to analyze the background effects can only be validated with observations. Thus, computer model validation efforts would benefit from the production o the HRMFI.

The HRMFI's computer-controlled measurement would be indispensable for reliable testing of the vast number of potential samples. The measurement procedure is programmed into the HRMFI computer, so that various standard tests can be repeated as often as desired. This feature would be useful in standardizing the BRDF testing and eliminating subjective errors. The computer control also adds flexibility to the HRMFI by allowing the test parameters to be modified in software to meet the mission requirements. The flexibility of the HRMFI will give ASL the test equipment to measure the BRDF for many applications in one field-compatible package.

The HRMFI can be used for reflectance measurements of any kind of surface with radiation over a wide range (250 nm to 14 μm). As the dependence on visible TV, FLIR and other sensors continues to increase, the effect of the background radiation will become more important. The key to predicting the background effects is in the measurement of the BRDF of the background constituents. Therefore, the measurement capability of the HRMFI will come into increased demand.

4.1 POTENTIAL COMMERCIAL APPLICATIONS

Several commercial applications for the HRMFI device have been identified. The HRMFI is a useful BRDF measurement system, and the data it gathers can be applied to many commercial uses. For example, industry uses satellite image data for various tasks,

including environmental damage assessment, storm damage assessment, and analyses of crop production. Because there is little BRDF data relating to plants, there is currently no way to analyze crop or vegetation in detail. With sufficient data from the HRMFI BRDF measurements, satellite data might be able to spot outbreaks of plant disease or pest infestations while they are still localized and controllable. Pollution effects could be detected earlier, thereby allowing corrective action before serious damage is done. The HRMFI data, therefore, would have important commercial applications.

4.2 POTENTIAL GOVERNMENT APPLICATIONS

The HRMFI has government applications in all projects that involve testing electro-optical/IR sensors or that involve reconnaissance. In the former case, all of the government developed and fielded sensors are limited in resolution performance by the contrast between the object and the background. The background and object radiance needs to be known before a sensor can be selected for a mission. The BRDF data that the HRMFI produces will allow the accurate prediction of the sensors mission performance. This will be essential for the successful deployment of any sensor. In reconnaissance applications, the sensor is almost always used near the limits of its resolution. Therefore, the BRDF, or radiance characteristics, of the background and object would aid in the reconnaissance effort. For example, a reconnaissance mission searching for a particular plant type (i.e., for drug interdiction, crop analysis, etc.) would use the BRDF data to look at the foliage at a particular time and elevation angle. This is a passive method of discrimination using the BRDF information such as that provided by the HRMFI. Finally, the HRMFI data could be used to test or detect advanced, multi-spectral camouflage for military applications. These examples demonstrate that the HRMFI data could be extremely useful for government applications.

SECTION 5
CONCLUSIONS

The design of a BRDF field measurement instrument is presented. The HRMFI will automatically measure the BRDF of any sample in three wavelength bands: UV (250 to 400 nm), mid-IR (3 to 5 μm), and far-IR (8 to 14 μm). Other bands in the 250 to 14,000 nm wavelength range (i.e., visible or NIR) can be added with minor modifications. The device is computer-controlled and requires little operator interaction once the sample is loaded in place. The synchronous detection and pyro-electric detectors assure high sensitivity (1 percent total diffuse or specular reflectivity is measurable). About 100 samples over the hemisphere are collected for each source angle on incidence. As there are 90 possible source angles of incidence, the BRDF is fully characterized with 9,000 individual reflectance measurements. This resolution is software-driven and can be increased or decreased without hardware modifications. The measurement is completely automatic and takes up to 1.5 hr, depending on the resolution. The system is designed so that the sample does not move during the measurement. This allows the HRMFI to characterize foliage without removal from the plant, or the HRMFI can be set directly onto the sample surface. This design meets all of the Phase I goals, and has low technical risk. It has been designed to use commercially available detectors, sources computers, and drive mechanisms. This increases the reliability and lowers the cost. The potential benefits of implementing the HRMFI have been discussed, and both potential commercial and government applications are plentiful.

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13. ABSTRACT *(Maximum 200 words)*

This Phase I small business innovation research (SBIR) final report describes the design of a man-portable, bidirectional reflectomter field instrument. The instrument can irradiate any sample surface with several spectral bands of radiation (ultraviolet, mid-infrared, and long-infrared) and measure the reflectance. The data from this reflectance measurement can characterize the bidirectional reflectance distribution function (BRDF) of the sample. The source illumination angle is varied, and a complete BRDF characterization can be obtained for each of a possible 90 illumination angles. The instrument is automatic and has self-test and self-calibrate features. The computer that controls the test gathers the digital data that can be transferred over a serial (RS232) or parallel (IEEE 488) data link. The vacuum sample stage is designed to securely hold foliage specimens in place without removal from the plant. This stage can be moved aside for other samples (i.e., rocks, limbs, ground, etc.). The low profile of the device allows the unit to rest directly on the sample to be testd permitting tests of road surfaces, grass fields, etc. This instrument has a sensor unit and a control/power unit. The unit can be powered from an automobile cigarette lighter or a 12-V battery belt.

14. SUBJECT TERMS

BRDF	Portable	Infrared	Automatic
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Field measurement	Ultraviolet	Reflectometer	

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